CALIBRATION OF BOTTOM TRAWL SURVEY VESSELS: COMPARATIVE FISHING BETWEEN THE ALFRED NEEDLER AND TELEOST ON THE SCOTIAN SHELF DURING THE SUMMER OF 2005

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ABSTRACT

Fowler, G.M. and M.A. Showell. 2009. Calibration of bottom trawl survey vessels: comparative fishing between the *Alfred Needler* and *Teleost* on the Scotian Shelf during the summer of 2005. Can. Tech. Rep. Fish. Aquat. Sci. 2824: iv + 25 p.

Adjustments to calibrate fish and invertebrate abundance estimates between two research survey vessels were determined using mixed-effects and fixed-effects modelling. The fixed-effects model assumes equal probability of a fish being available for capture between the two vessels for a given paired tow set, while the mixed-effects model assumes equal probability over the population of sets, including an estimate of within-set variability as random error. The mixed-effects approach appeared superior to the fixed-effects approach, being better able to resolve the high variability between sets characteristic of the stratified-random survey design in which the calibration experiment was conducted.

Differences in catchability with length of animals was pervasive, the greatest differences in catchability between vessels being associated with the smallest animals. The influence of length on catchability was best portrayed as a curvilinear relationship, as catchabilities tended to plateau for animals over about 26cm.

For some species catchabilities between vessels differed according to the time of day and depth of a tow, though in most cases the differences were of fairly small magnitude.

RÉSUMÉ

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Nous avons utilisé un modèle à effets fixes et un modèle à effets mixtes pour déterminer les ajustements requis pour étalonner les estimations de l'abondance des poissons et des invertébrés entre deux navires de recherche. Le modèle à effets fixes suppose que la probabilité de la disponibilité d'un poisson à la capture, par l'un ou l'autre navire, pour un ensemble donné de traits jumelés est égale, alors que le modèle à effets mixtes suppose que cette probabilité est égale pour l'ensemble des traits jumelés, y compris une estimation de la variabilité dans les traits comme erreur aléatoire. Le modèle à effets mixes semble donner de meilleurs résultats que le modèle à effets fixes : il a permis de traduire la variabilité élevée entre les traits caractéristique du protocole de relevé aléatoire stratifié où s'inscrit l'expérience d'étalonnage.

Les différences sur le plan de la capturabilité selon la longueur des organismes sont marquées. Les plus grandes différences entre les navires se situent au niveau des organismes les plus petits. Une relation curvilinéaire illustre le mieux l'effet de la longueur sur la capturabilité, celle ci ayant tendance à plafonner pour les organismes de plus de 26 cm environ.

Pour certaines espèces, les potentiels de capture variaient d'un navire à l'autre selon l'heure du jour et la profondeur du trait, bien que dans la plupart des cas, les différences étaient assez petites.

INTRODUCTION

Demersal surveys are conducted on Canada's Scotian Shelf (NAFO Divisions 4VWX) to provide ecological information on species inhabiting the continental shelf and slope waters off New Brunswick and Nova Scotia. The survey design emphasizes the estimation of commercial groundfish abundance and distribution (Halliday, 1981), the stratification focused largely on the distribution of cod, haddock and yellowtail flounder, but is also utilized to collect data on invertebrate and non-commercial species. Beyond abundance and distribution estimates, these surveys provide information on species associations, predator-prey relationships, and basic biology of species sampled.

From 1982 through 2003 the Scotian Shelf Summer (4VWX July) survey was conducted solely by one stern trawler, the Canadian Coast Guard Ship (CCGS) *Alfred Needler*. This vessel was also used to conduct three other major standard surveys – the Gulf of St Lawrence August survey, the Georges Bank February survey, and the Scotian Shelf March survey. In August 2003 the *Needler* was seriously damaged by a fire while at sea. Repairs to engine and generator systems were lengthy, and the vessel was not ready to resume work until late August, 2004. Over the intervening period any standard surveys that had been the responsibility of the *Needler*, including the 2004 July Scotian Shelf survey, was conducted by another DFO stern trawler, the CCGS *Teleost*. However, no data were available to quantify relative catchabilities of species between these two vessels. Thus the *Teleost* contribution to these surveys could not be used to gauge trends in abundance, or in any other time series context that required an assumption of equal catchabilities between vessels.

Aside from the issue of how to interpret a single year of data provided by the *Teleost*, over the period that the *Needler* was undergoing repair and refit, it was recognized that the 24 year old vessel might not be available on a consistent basis for future work. The *Teleost* was available as a replacement, but if used would also constitute a break in the time series, with no way to interpret trends in abundances or various other biological parameters from the *Needler* to the *Teleost*. To address this issue an extensive series of comparative fishing experiments were conducted in 2004 and 2005, covering five standard groundfish surveys conducted annually in Atlantic Canada. The purpose of this document is to report on the results of one of these experiments – the Scotian Shelf Summer (4VWX July) survey conducted in 2005.

Both vessels conducted most of the 2005 Scotian Shelf Summer survey in unison, each collecting standard survey data according to the defined protocols for the survey. Sampling included identification, weighing and enumeration of fish and invertebrate species. Typically the sizes of individual specimens were measured, and individuals from size-stratified subsamples were weighed. Large catches (over 200 individuals of a species) might be subsampled for size-frequencies and the results of individual measurements extrapolated to the whole catch on the basis of subsampled versus total sample weight.

Past calibrations of survey vessel catchabilities in waters covered by the *Needler* have used various modelling approaches to accomplish the task. The differences are primarily concerned with attempts at dealing with the large magnitudes of variance between sets characteristic of these surveys. A progression can be summarized from jackknife estimation of simple ratios of Vessel.1/Vessel.2 (Koeller & Smith, 1983); assuming a linear model with a beta distribution for the ratio of Vessel.1/(Vessel.1 + Vessel.2) (Fanning, 1985); a generalised linear model relating the logged abundance of one vessel to the other and disregarding sets for which the catch from either vessel was zero (Nielsen, 1994); a generalised linear model with a binomial distribution for the ratio of Vessel.1/(Vessel.1 + Vessel.2), plus estimating the overdispersion for use as a scale parameter and disregarding sets only where the catches from both vessels were zero (Benoit and Swain, 2003); and a mixed-effects generalised linear model (Cadigan et al, 2006; Benoit, 2006). The *Needler* itself was one of the subject vessels in all but the first study.

The progression represents a succession of attempts to address the problematic variance associated with survey sets. In all cases except the mixed-effects model, preliminary analyses to identify and resolve outliers were a requirement. In the current study we continue this progression in an attempt to account for the variance within tow pairs, by the adoption of a generalised linear mixed-effects model similar to that presented by Cadigan et al (2006), and compare results to a generalised linear fixed-effects model of similar type to that presented by Benoit and Swain (2003). Comparison of fixed-effects and mixed-effects model results parallels that of Benoit (2006), but using a different modelling strategy. The Benoit (2006) study also incorporated much of the Scotian Shelf paired-trawl data used in our study, along with a dedicated southern Gulf of St. Lawrence paired-trawl experiment with the same vessels. Cadigan et al (2006) also compared fixed-effects and mixed-effects models, but the paired tows were conducted by sister ships with a Campelen shrimp trawl and only seven species of fish were considered, whereas this study extends to a multitude of species (including invertebrates) caught by non-sister ships using a Western IIa bottom survey trawl.

METHODS

The Scotian Shelf Summer 2005 survey was conducted by both vessels according to the standard stratified-random protocol (Koeller, 1981; Doubleday, 1981) applied to surveys since the early 1970's. At the majority of comparative stations the *Needler* and *Teleost* towed side-by-side on the same course, ideally not more than 0.5 nautical miles apart. To the extent possible the depth range sampled by each vessel was the same for each tow. The position of each vessel during the comparative tows (i.e. port or starboard) was alternated on a tow-by-tow basis. On the shelf edge, where towing side-by-side would result in considerable differences in depths sampled, one vessel towed ahead of the other. The vessels were positioned such that the tows did not overlap, and the lead ship was alternated on a tow-by-tow basis.

Standard 30 minute tows at a speed of 3.5 knots were attempted at each survey station. While tow duration on occasion was shortened due to rough bottom conditions, tows less than 20 minutes in duration were not considered valid. Catches were sampled as per standard bottom trawl survey protocols, with numbers recorded by species and length. Weights were also recorded by species, and some species were subsampled for both length and weight, but only count data is treated here. All counts were standardized for analysis to an ideal 1.75 nautical miles of swept area. This is the same adjustment as historically applied to survey catches for the purpose of estimating abundance.

A number of species were poorly represented. Several were combined into groups of related species for analysis – different and/or possibly different species of rocklings, lanternfish, hookear sculpins (possibly all Atlantic hookear), grenadiers, and eelpouts (possibly all Vahl's). No species (or species group) represented by less than 25 specimens from either vessel was treated, including some species (e.g. cusk, offshore hake, cunner, mackerel, lumpfish) that sometimes feature more prominently in surveys than they did with respect to the available paired tows in 2005. A total of 61 species remained after applying the 25-fish selection criterion. Length-based analyses were restricted to fish (and squid) species with 200 or more individual length measurements. Non-swimming invertebrates were only addressed in terms of total numbers, regardless of whether the sampling protocol included individual measurements. None of the poorly represented related-species groups described above were treated for length effects. Species of recent assessment interest that were not investigated for length effects because of the 200-measurements criterion included halibut, wolffish, monkfish, pout, hagfish and several skate species (smooth, little, winter). Length-based analyses were applied to 27 fish and 1 squid species.

The vessels worked around-the-clock throughout the survey, with sampling of tows for the weights and numbers caught by species, and numbers by length, conducted on board the vessels by two teams of field staff per vessel. Staff were assigned to alternating 6-hour periods, termed watches, in order to maintain sampling on a constant basis without undue fatigue. The survey was also comprised of two 2-week periods, termed survey legs, for which most field staff were replaced with new personnel. Thus we had a total of 8 field staff teams sampling independently over the course of the entire survey. Historically, variations in the validity of certain sampling parameters (e.g. identification of less common species) have been noted between watches. Thus preliminary analyses of watch-specific relative catchabilities were conducted to flag species for which results may be confounded by inconsistency in sampling protocols or species identification. Due to the 6-hour alternation of the field teams, disparities in sampling methodology between watches on the same vessel evidence themselves as sharp changes in abundance over successive 6-hour time periods, producing a visibly distinct 'zigzag' pattern when summarized graphically over the four 6-hour blocks. Abundance patterns were examined for such extreme discontinuities over the four watch periods, which might indicate that a particular watch was not accounting for a species. A similar check was made for very extreme but constant relative catchabilities across all watch periods between vessels, which might indicate that both watches of one vessel were not accounting for a species. And finally, where a species was common throughout both legs

of the survey, watch patterns in relative catchabilities were compared between legs to check for extreme inconsistencies. Species exhibiting suspect patterns were then discussed with watch personnel to determine if sampling or identification issues might be responsible for the patterns.

Four species and four species groups were flagged by the preliminary analyses of watch-specific catchabilities as likely confounded by sampling or identification problems. All eight of these involved invertebrate species that have only recently been part of the survey sampling protocol – sea cucumbers, sand dollars, sea urchins, starfish, Iceland scallops, Jonah crabs, deep-water shrimp, and pink shrimp. Sand dollars were dropped from consideration. The identification concerns for Iceland scallops and Jonah crabs may also confound results for sea scallops and rock crabs, respectively.

In addition to the sampling/identification issues raised by examination of watch-specific catchabilities, it is also known that white and red hake have often been confused with each other in the past. If such a problem still exists, it could be a confounding factor without showing up as a watch effect. Also, during consultations with staff on issues of sampling and identification it was further noted that little skate and winter skate may be confused with each other, which could compromise results for both species.

For all analyses we assumed a binomial distribution for the Needler catch, with probability of success defined as the ratio of the Needler catch to the catches of the Needler and Teleost combined,

$$\text{logit}\left(\text{Catch}_{\text{Needler}}/(\text{Catch}_{\text{Needler}}+\text{Catch}_{\text{Teleost}})\right) = \text{logit}(p_i) = \beta_{\text{vessel}}$$

For analyses of species with no length measurements, only those set pairs containing some catch for a species by at least one of the vessels were included in analyses (no set pairs with 0 catches of a species by both vessels). For analyses that include testing for length effects, only those set pairs containing some catch for a species by both of the vessels were included in analyses (no set pairs with 0 catches of a species by either vessel). This filter negates tow pairs where the species might not be equally available to capture by both vessels due to spatial distribution, such as in marginal areas for that species. This differs from the Benoit and Swain (2003), Benoit (2006), and Cadigan et al (2006) approaches for species with potential for length effects, where set pairs with one null tow were included.

The linearity of the regression relationship between relative catch and length, for any species for which length was considered, was tested against a quadratic polynomial of length, which we call LS. If the quadratic term demonstrated significantly more explanatory power than the linear term alone, the quadratic term was retained in the model. This will differ from past approaches, including Benoit and Swain (2003), Benoit (2006), and Cadigan et al (2006), where changes in catchability with length were assumed linear. Note that in cases where the quadratic component demonstrated significance, any statistical tests associated with the linear component would be

compromised by colinearity with the quadratic component. In these cases the linear coefficient is presented without any associated statistical test results.

For all models, depth and a diel variable (2100-0600/0700-2000 night/day split) were tested as fixed effects. The choice of time periods for the diel variable was motivated by an ad hoc examination of 1970-2005 Summer survey catchabilities by hour for several species, and the correspondence of these historical patterns with dark and light periods of the day. Standard length (the length of a fish from the tip of the snout to the base of the caudal fin, or the dorsal length of the mantle for squid) was tested as a fixed effect in models for species with over 200 measurements. The full model can be expressed as

$$\text{logit}(p_i) = \beta_{\text{vessel}} + \text{period} + \text{DEPTH} + \text{FishLength} + \text{LS}.$$

Calibration coefficients were estimated from both fixed-effects and mixed-effects models using S-Plus 7.0 with the MASS library (Venables and Ripley, 2002). The main difference between fixed-effects and mixed-effects modelling was the treatment of the variance. In the fixed-effects models the variance was estimated and the dispersion accounted for when testing for significance (i.e. approximately binomial, dispersion not assumed to be 1). In the mixed-effect models the within-paired-tow variance was assumed to be a normally distributed random variable (random effect), with the remaining variance assumed to be binomial (dispersion = 1).

The process of model selection differed slightly between the two modelling approaches. In both cases we started with full models (all terms considered), and then conducted single term deletions/additions to gauge the explanatory relevance of the terms. The Akaike Information Criteria (AIC) of successive fixed-effects models were compared using a Chi-square test (Chambers and Hastie, 1993) to determine the most suitable hierarchy of main effects for a given species, with iterative removal of least relevant terms. The probabilities of t tests were compared between the terms of mixed-effects models to identify the least significant effect for removal in successive models. With both approaches, terms demonstrating significance at $P<=0.05$ were retained in the final models from which calibration coefficients were derived. Some notion of the potential for the different methods of term selection to give divergent results between mixed-effects and fixed-effects modelling was provided by conducting a parallel series of fixed-effects models, on length-based species, using the same term selection method as mixed-effects models (i.e. based on the probabilities of t tests).

Where modelling indicated that more than one fixed effect was significant for a species, the model was expanded to test for interactions. These results are not presented, but any significant interactions are noted.

A major feature of the fixed-effects modelling methodology that differs from past approaches for calibration, was that we did not attempt to identify and remove outliers from models. During initial analyses it appeared that the most problematic outliers were associated with discordant pairs of tows, which the random effect in the mixed-effects

model resolved. Thus leaving the data as is for both approaches would demonstrate if mixed-effects modelling was robust to the confounding role of outliers in this type of experiment. One exception to this approach was the fixed-effects model for cod, in which an extreme outlier set was readily apparent. In this case two fixed-effects models were generated, one with and one without the anomalous set.

As an inferential test of the robustness of the glmmPQL models, we conducted parallel GLIMMIX (SAS 9.1) models of the length-based analyses. The GLIMMIX procedure is analagous to glmmPQL, differing in some details of the fitting methodology, and using Wald-type significance testing of fixed effects, which some regard as more conservative than the t tests used with glmmPQL.

To give some idea of the practical significance of the calibration exercise, we applied adjustments to the 2004 July survey conducted by the Teleost on the Scotian Shelf while the Needler was undergoing refit. Independent of the paired tows in 2005 from which adjustments were determined, the 2004 survey provides a means of gauging the ramifications of calibrating estimates (or not). Note that the calibrated estimates are derived solely from counts of measured fish. Sometimes not all individuals of a species from a tow get attributed to lengths due to sampling error (failing to measure some animals), such that the estimated total number can differ from that based on measured fish. Usually the difference is trivial as sampling errors tend to involve very small numbers of animals, but sometimes it can be of concern. In our data sampling error was generally not a problem, but did produce a serious difference between total and measured counts for dogfish, sufficient to confound a simple comparison of uncalibrated to calibrated catch estimates. Thus in addition to the conventional uncalibrated estimates of number per tow, we also computed parallel uncalibrated estimates based on number measured per tow.

RESULTS and DISCUSSION

A total of 174 paired fishing sets were made during the July 2005 survey. The experimental design was intended to ensure the fishing operations of the two vessels was very similar. For depth fished, this was true, with paired t tests showing no significant difference between the two vessels. A difference was found for distance towed, with the CCGS Alfred Needler towing a significantly longer distance than the CCGS Teleost. However, this difference was small (1.4%). In four cases, distance towed differed by more than 20%, and these sets were excluded from further analysis. The locations of the 170 valid set pairs used in this analysis are depicted in Figure 1.

Benoit (2006), analysing results of the parallel Needler-Teleost calibration study in the southern Gulf of St Lawrence survey, used independent models for each effect (length, depth, diel effects), rather than conducting full models on all effects simultaneously to establish significance of terms. During preliminary stages of analysis

of the Scotian Shelf Summer survey we compared independent single-effect models as presented by Benoit (2006) to all-effects models. We found similar numbers of significant effects overall, but a great many examples of divergent results, mostly involving the significance of the intercept (the vessel effect). We believe that most of the divergences in results between single-effect and all-effects models can be attributed to the distributions of the unconsidered fixed effects within the considered fixed effect distributions in single-effect models. Thus we did not feel that single-effect models should be used to determine significant effects.

Results for sparsely sampled and non-swimming species, where length effects were not considered, are summarized in Table 1 (fixed-effects modelling) and Table 2 (mixed-effects modelling). Sampling and identification issues are flagged as well in Table 2. Occurrences of NaN probabilities and 0 degrees of freedom denote inability to achieve a test of significance. These are all associated with species exhibiting too few observed count pairs, in which both vessels had counts greater than 0, to resolve with a mixed-effects binomial model. For many, if not all, of the species in these tables, the low number of animals and/or non-zero tows available for analysis should be considered before assuming results to be valid. We would extend this cautionary note to apparently significant effects, as the number of tests in these tables are sufficient to produce a comparable number of significant tests by chance alone. Thus Tables 1 and 2 might be generally considered to represent cases of insufficient data to draw conclusions. Results for length-based models are summarized in Table 3 (fixed-effects modelling) and Table 4 (mixed-effects modelling).

In comparing the 28 length-based models between glmmPQL and GLIMMIX, results were consistent for 23 models. Non-trivial differences in results were observed for 5 models, all cases of GLIMMIX adding one significant term to a model relative to glmmPQL. These divergences between methods appeared to reflect differences in fitting, rather than simple shifts in probabilities between t test (glmmPQL) and Wald-type (GLIMMIX) hypothesis testing. The length effect for silver hake and sandlance, both recognized as problematic fits during glmmPQL modelling, was fit by GLIMMIX as a quadratic. A linear length effect was determined by GLIMMIX for longhorn sculpin and capelin, neither of which presented any significant effects with glmmPQL modelling. And depth was added as a significant effect by GLIMMIX for herring. As an overall test of robustness, the consistency in results for most models is encouraging.

Comparing Methods of Analysis

We noted far more parameters demonstrating significance at $P<=0.05$ with fixed-effects modelling than mixed-effects modelling. Significant effects in final models totalled 61 with fixed-effects models versus 30 with mixed-effects models for length-based species (not counting quadratic extensions to the length parameter), and 13 versus 6 for non-length-based species. The two modelling approaches tended to correspond in their portrayal of length effects to a far greater degree than other effects. Parameters attaining significance in fixed-effects models but not mixed-effects models showed a bias toward those effects associated with set variance (intercept, period, and depth). This

suggests that for fixed-effects modelling, some of the apparent differences in catchability between vessels may be misattributed variance between sets, which the mixed-effects modelling treats as random variation.

The parallel series of fixed-effects models on length-based species using t test significance for term selection revised the final model for only one of the 28 species (yellowtail flounder), and the revision was minor, changing the calibrated estimate by about 3%. This suggests that differences between fixed-effects and mixed-effects modelling in the process of ranking relevance of effects had little influence on results.

Considering just those species subject to calibration by both fixed-effects and mixed-effects modelling (disregarding fixed-effects models for the 7 species showing no significant parameters in mixed-effects models), absolute differences between uncalibrated and calibrated estimates averaged out to about 40% of the uncalibrated estimates (Table 5, and using the results from the cod model with the outlier removed). However much of the difference was due to species for which the survey was not explicitly designed. Focusing on typical groundfish species (cod, haddock, flatfish species, dogfish), mixed-effects modelling usually produced adjustments within 10-15% of the uncalibrated estimates. Adjustments from fixed-effects models remained higher, however, averaging in the 30% range.

Comparisons of Vessels

We believe the calibrations from mixed-effects modelling to be more reliable than those derived from fixed-effects modelling, being less susceptible to the influence of set variability in general, and outliers within set pairs. For the purpose of examining differences in catchability between vessels related to specimen length, diel and depth effects we chose to focus on predictions from mixed-effects models.

For length-based analyses with all terms in the models, we found significant ($P<=0.05$) differences in catchability between vessels for most species. Differences in catchabilities at length predominated as a significant fixed effect. Significant intercepts at $P<=0.05$ are usually associated with significant differences in catchability at length.

Most of the instances of a significant length effect appear to fall into three broad categories. Typical groundfish species (cod, turbot, plaice, witch, yellowtail, dogfish) for which the survey was originally designed give a mix of patterns with respect to shapes and slopes, but with narrower ranges in their upper/lower limits of relative catchability than other species (Figure 2). Higher catchabilities for the Needler are usually associated with smaller or larger animals (even both for witch), while the vessels exhibit closer catchabilities over the more central majority of lengths. Very small and/or very sedentary species (rosefish, mailed sculpin, sandlance, shanny) are characterized by low Needler catchabilities for the smallest fish grading to high Needler catchabilities for the largest fish, with extensive ranges between the lower and upper catchabilities (Figure 3). The

more pelagic species (herring, silver hake, squid, redfish, pollock) give a mix of catchability patterns and ranges (Figure 4). Redfish and herring are characterized by higher Needler catchabilities at smaller sizes grading steeply to higher Teleost catchabilities at larger sizes. Needler catchabilities of silver hake and squid increase with length, but over very narrow ranges. Pollock, distinguished by its relatively large size, shows very low Needler catchability that only approaches that of the Teleost for the largest fish. The eel-like blenny and very deep-water longfin hake (Figure 4) are too unique to categorize.

Examining catchability by length across all 17 species characterized by significant length effects in mixed-effects models (Figure 5) shows a broad pattern of lower Needler catchabilities for the smallest fish rising sharply to higher Needler catchabilities in the 15-25cm range, followed by a drop to similar catchabilities for fish over 25cm (the emphasized length range from 8-46cm is represented by 5 or more species). Many of the species-specific patterns reflect this broad trend, the particular shape varying according to the length range of the species. In overview, these results suggest the largest differences in catchability of the vessels for fish under about 26cm.

Diel differences in relative catchability significant at $P <= 0.05$ were exhibited for seven species in mixed-effects models (Figure 6). Most of the differences were of small magnitude, and no large differences were associated with typical groundfish species. Large differences were associated with blenny (higher Needler catchabilities during the day and lower Needler catchabilities at night) and alewife (much higher Needler catchability at night). Five species demonstrated trends in relative catchability with depth that were significant at $P <= 0.05$ (Figure 7), all but one (rosefish) of fairly small magnitude.

Mixed-effects model tests for interactions ($P <= 0.05$) revealed some concern with redfish calibrations. Interaction of diel period with both length and depth proved significant. It appears we only see a relationship between catchability and either redfish length or tow depth for daylight fishing. The relationship disappeared at night. This suggests that the difference in catchability may be related to a visual response of redfish to the gear. Unfortunately visual features of the survey gear, such as colouration of components, was not a consideration in the survey design.

The Needler generally caught more fish than the Teleost (Table 6), as also observed by Benoit (2006). Of the most abundant species caught in the Summer survey (those considered for length-based analyses), and disregarding cases where either of a pair of sets was zero, the Needler had more sets in which a given species was more abundant than their associated Teleost sets for 21 of the 28 species treated (X-square = 6.0357, $p = 0.014$, null probability of 0.5). Teleost abundances were greater for 6 species (1 tie). Overall numbers caught (summed over sets) don't necessarily reflect this situation for all species, as an anomalously large set can overwhelm a given sum.

Comparing the results of this study with that of Benoit (2006), we found notably more significant effects overall, but especially more significant length effects. We believe

inconsistencies in results between studies derive primarily from the difference in our approach to handling the length variable. We tested the animal length effect for curvilinearity, treating the term as a quadratic where appropriate. The Benoit (2006) study only considered length as a straight-line regression term. Essentially half the species showing a significant difference in catchability between vessels in our study were characterized by curvilinear patterns in catchability with length. In some cases the resulting curvature was so pronounced as to produce a null straight-line regression. Witch flounder and blenny, for which no length effect was found in Benoit (2006), are extreme examples of such curvature (see Figures 2 and 4). Another possible source of diverging results between studies was our use of all-term models to determine effects, whereas Benoit (2006) used separate models for each fixed effect. Where more than one fixed effect is relevant, discerning a given effect may be confounded by the influence of unconsidered effects.

CONCLUSIONS

The generally higher catchabilities of the Needler should be considered in light of the different selectivities by length of the two vessels. The Needler demonstrated higher catchabilities than the Teleost for fish in the 15-25cm range. As almost half of all the measured specimens in the comparative study fell into this length range, the overall relative catchability appears to reflect this preponderance of 15-25cm animals.

From a practical standpoint, most of the adjustments for catchability are of less magnitude than the standard errors of abundance estimates. This is especially true for calibrations based on mixed-effects models, where only 5 of the 28 species considered for length-based analyses would pose adjusted estimates that differed from their unadjusted counterparts by more than the standard errors of the estimates. And none of the 5 species requiring the larger adjustments (pollock, longfin hake, sandlance, blenny, sea poacher) are regarded as species for which the survey was intended. With fixed-effects modelling, 11 species would receive adjustments of larger magnitude than their standard errors. With respect to typical groundfish species (cod, haddock, flatfish species, dogfish) adjusted estimates from mixed-effects models average within 10% of unadjusted estimates, while those from fixed-effects models average within 30%.

We believe the fixed-effects modelling is vulnerable to spurious influences of set variability, especially for species represented by smaller numbers of sets. It also seems highly sensitive to outliers, even with large numbers of sets as demonstrated by the cod models. Lesser sensitivity of mixed-effects models to outliers in comparative survey data was also noted by Benoit (2006) and Cadigan et al (2006). We therefore believe that the mixed-effects models provide more appropriate coefficients for adjusting Teleost catches to Needler equivalents.

The choice of modelling approach might be debated. Thus we have presented the coefficients for both fixed and mixed-effects final models (restricted to significant terms only) in Tables 7 and 8, giving the researcher or assessor the choice of how to address

Teleost catchabilities for a given species. Table 9 is just a simple lookup table with the suggested calibration coefficients from the mixed-effects models. An adjustment equation takes the same form in all cases:

Calibrated Catch of Teleost = Catch of Teleost * exp(Intercept + (Diel Period Coefficient * Diel value) + (Depth Coefficient * Depth) + (Linear Length Coef * Length) + (Quadratic Length Coef * Length^2)

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TABLE 1. Traditional fixed effects model results for sparsely sampled species (no consideration of length effects).

Species	N	Intercept	SE	T	P	Period	SE	T	P	Depth	SE	T	P
HALIBUT	39	-0.44237	0.466	-0.950	0.349	0.65456	0.447	1.463	0.152	0.00270	0.005	0.565	0.576
WOLFFISH	44	-0.37138	0.733	-0.507	0.615	-0.44660	0.519	-0.861	0.394	0.00987	0.012	0.809	0.423
SMOOTHSKATE	37	0.23348657	0.533	0.438	0.664	0.389898701	0.601	0.648	0.521	-0.000858486	0.006	-0.144	0.886
LITTLESKATE	13	0.148645571	0.904	0.164	0.873	15.5368029	1005.108	0.015	0.988	0.003069255	0.014	0.218	0.832
WINTERSKATE	29	-0.875354024	0.581	-1.507	0.144	0.457363262	0.648	0.705	0.487	0.010230345	0.010	1.077	0.292
MONKFISH	49	0.71561	0.385	1.859	0.069	-0.60772	0.388	-1.567	0.124	-0.00369	0.003	-1.439	0.157
POUT	28	-2.231798853	0.858	-2.600	0.015	-0.234690066	0.470	-0.500	0.622	0.029343707	0.013	2.315	**0.029**
SHAD	14	2.46155	2.384	1.033	0.324	-0.00601	2.082	-0.003	0.998	-0.02742	0.014	-1.999	0.071
ROCKLING	28	0.07675	0.905	0.085	0.933	-0.21507	0.532	-0.404	0.689	0.00140	0.009	0.150	0.882
LANTERNFISH	14	0.64494	1.215	0.531	0.606	-0.94038	0.653	-1.440	0.178	-0.00313	0.005	-0.618	0.549
HAGFISH	30	0.83127	0.834	0.997	0.328	1.36824	0.655	2.090	0.046	-0.00507	0.007	-0.736	0.468
HOOKEARSCULPIN	30	-0.52282	0.795	-0.658	0.516	1.14009	0.845	1.349	0.189	0.00080	0.011	0.074	0.942
GRENADIER	15	-0.81490	0.821	-0.992	0.341	0.27194	0.471	0.577	0.574	0.00319	0.003	1.023	0.327
EELPOUT	31	0.91904	0.738	1.246	0.223	0.23074	0.378	0.610	0.547	-0.00434	0.008	-0.554	0.584
WHITE BARRACUDINA	12	-0.67853	1.824	-0.372	0.719	1.58921	0.740	2.148	0.060	-0.00116	0.008	-0.145	0.888
DEEPWATERSHRIMP	46	-0.35029	0.532	-0.658	0.514	-1.11940	0.434	-2.581	**0.013**	0.01152	0.004	2.882	**0.006**
PINKSHRIMP	102	1.79056	0.425	4.217	**0.000**	0.29365	0.358	0.820	0.414	-0.01349	0.006	-2.396	**0.018**
JONAHCRAB	57	1.75265	0.664	2.638	**0.011**	-0.12215	0.526	-0.232	0.817	-0.01789	0.007	-2.438	**0.018**
ROCKCRAB	21	-0.71481	0.753	-0.949	0.355	-0.00771	0.619	-0.012	0.990	-0.00463	0.016	-0.292	0.774
LYRECRAB	57	0.80705	0.775	1.042	0.302	0.25204	0.359	0.702	0.486	-0.01562	0.015	-1.013	0.315
STONECRAB	30	0.68790	0.553	1.245	0.224	0.59347	0.430	1.381	0.179	-0.00461	0.004	-1.199	0.241
SNOWCRAB	87	1.21442	0.279	4.351	**0.000**	-0.86993	0.197	-4.419	**0.000**	-0.00273	0.003	0.807	**0.422**
TOADCRAB	42	-0.25331	1.576	-0.161	0.873	-0.30209	0.698	-0.433	0.667	0.03087	0.031	0.985	0.331
REDCRAB	8	-2.05562	0.996	-2.065	0.094	1.04466	0.352	2.965	**0.031**	0.00465	0.004	1.147	0.303
LOBSTER	40	-0.44649	0.348	-1.282	0.208	0.03734	0.226	0.165	0.869	0.00353	0.005	0.775	0.443
HERMITCRAB	63	1.32045	0.392	3.367	**0.001**	0.51509	0.345	1.494	0.140	-0.01393	0.007	-2.026	**0.047**
SEASCALLOP	40	0.63158	0.553	1.142	0.261	-0.71785	0.395	-1.817	0.077	0.00319	0.009	0.344	0.733
ICELANDSCALLOP	29	0.26288	0.684	0.384	0.704	0.37913	0.481	0.789	0.438	0.01105	0.016	0.681	0.502
STARFISH	152	0.05560	0.270	0.206	0.837	-0.14659	0.237	-0.619	0.537	-0.00358	0.003	-1.273	0.205
NORTHERNSEAURCHIN	42	-1.68392	10.664	-0.158	0.875	3.06227	6.968	0.439	0.663	0.03560	0.180	0.198	0.844
SEACUCUMBER	60	0.49983	0.678	0.737	0.464	0.20659	0.395	0.523	0.603	-0.02118	0.016	-1.357	0.180

TABLE 2. Mixed effects model results for sparsely sampled species (no consideration of length effects).

Species	N	Intercept	SE	DF	T	P	Period	SE	DF	T	P	Depth	SE	DF	T	P	Comments
HALIBUT	39	-0.87670	0.598	1	-1.467	0.381	1.16553	0.473	1	2.464	0.245	0.00562	0.005	1	1.073	0.478	
WOLFFISH	44	-1.19237	0.835	2	-1.428	0.289	0.33557	0.601	2	0.559	0.633	0.01771	0.013	2	1.380	0.302	
SMOOTHSKATE	37	0.20875	0.575	0	0.363	NaN	0.54626	0.602	0	0.908	NaN	-0.00189	0.006	0	-0.311	NaN	
LITTLESKATE	13	-0.06835	0.969	0	-0.071	NaN	24.30890	0.867	10	28.038	**0.000**	0.00883	0.014	10	0.652	0.529	
WINTERSKATE	29	-0.49052	0.725	0	-0.677	NaN	0.07824	0.702	0	0.111	NaN	0.00516	0.010	0	0.523	NaN	
MONKFISH	49	0.71562	0.385	4	1.859	0.137	-0.60772	0.388	4	-1.567	0.192	-0.00369	0.003	4	-1.439	0.224	
POUT	28	-2.23178	0.858	0	-2.600	NaN	-0.23469	0.470	25	-0.500	0.622	0.02934	0.013	0	2.315	NaN	
SHAD	14	3.36765	2.505	0	1.344	NaN	-0.23039	2.137	11	-0.108	0.916	-0.03748	0.016	11	-2.362	**0.038**	
ROCKLING	28	0.07675	0.905	0	0.085	NaN	-0.21507	0.532	25	-0.404	0.689	0.00140	0.009	0	0.150	NaN	
LANTERNFISH	14	0.11634	0.855	0	0.136	NaN	-0.77946	0.612	11	-1.273	0.229	-0.00194	0.004	11	-0.441	0.668	
DRAGONFISH	3																
BLACKDOG	5	3.86556	2.897	0	1.334	NaN	NA	NA	NA	NA	NA	-0.01026	0.009	3	-1.137	0.338	
HAGFISH	30																
HOOKEARSCULPIN	30	0.17859	0.750	0	0.238	NaN	0.72148	0.835	27	0.864	0.395	-0.00569	0.009	27	-0.665	0.512	
GRENADIER	15	-0.81490	0.821	0	-0.992	NaN	0.27194	0.471	12	0.577	0.574	0.00319	0.003	0	1.023	NaN	
EELPOUT	31	0.77027	0.798	0	0.965	NaN	-0.09723	0.462	28	-0.211	0.835	-0.00308	0.009	28	-0.346	0.732	
WHITE BARRACUDINA	12	-1.22196	1.989	0	-0.614	NaN	1.75662	1.301	9	1.350	0.210	0.00365	0.009	0	0.426	NaN	
DEEPWATERSHRIMP	46	-0.32197	1.208	3	-0.267	0.807	-0.59983	1.033	3	-0.581	0.602	0.01106	0.009	3	1.208	0.314	Sampling concern
PINKSHRIMP	102	0.84420	0.696	17	1.213	0.242	-0.54518	0.532	17	-1.025	0.320	-0.00292	0.008	17	-0.372	0.714	Sampling concern
JONAHCRAB	57	2.07152	0.779	7	2.659	**0.033**	0.10301	0.603	7	0.171	0.869	-0.02312	0.009	7	-2.714	**0.030**	ID concern
ROCKCRAB	21																
LYRECRAB	57	1.43869	0.762	5	1.888	0.118	-0.11591	0.539	5	-0.215	0.838	-0.01588	0.014	5	-1.147	0.303	
STONECRAB	30	0.74312	0.572	0	1.299	NaN	0.61982	0.444	27	1.396	0.174	-0.00523	0.004	27	-1.319	0.198	
SNOWCRAB	87	1.41785	0.260	1	5.448	0.116	-0.60383	0.226	83	-2.671	**0.009**	-0.00681	0.003	1	-2.385	0.253	
TOADCRAB	42																
REDCRAB	8	-2.05562	0.996	0	-2.065	NaN	1.04466	0.352	5	2.965	**0.031**	0.00465	0.004	5	1.147	0.303	
LOBSTER	40																
HERMITCRAB	63	1.25217	0.396	2	3.158	0.087	0.45121	0.370	2	1.220	0.347	-0.01146	0.006	2	-1.801	0.214	
SEASCALLOP	40	0.55407	0.680	1	0.815	0.565	-0.41705	0.568	1	-0.735	0.597	0.00631	0.011	1	0.597	0.657	
ICELANDSCALLOP	29	0.00704	0.780	0	0.009	NaN	0.42531	0.704	26	0.604	0.551	0.01441	0.011	26	1.360	0.185	ID concern
STARFISH	152	0.59357	0.315	45	1.883	0.066	-0.42496	0.270	45	-1.573	0.123	-0.00542	0.003	45	-1.860	0.069	Sampling concern
NORTHERNSEAURCHIN	42	-1.68392	10.664	1	-0.158	0.900	3.06227	6.968	38	0.439	0.663	0.03560	0.180	1	0.198	0.876	Sampling concern
SEACUCUMBER	60	0.42441	0.736	2	0.577	0.622	-0.47334	0.529	2	-0.896	0.465	-0.00313	0.014	2	-0.222	0.845	Sampling concern

TABLE 3. Traditional fixed effects model results for species sampled sufficiently to consider length effects.

Species	N	Intercept	SE	T	P	Period	SE	T	P	Depth	SE	T	P	Length	SE	T	P	quadratic	SE	T	P
COD	650	0.90226	0.561	1.609	0.108	1.76777	0.142	12.432	**0.000**	0.01142	0.003	4.212	**0.000**	-0.16591				0.00171	0.000	5.941	**0.000**
HADDOCK	1487	-0.64872	0.122	-5.308	**0.000**	0.00678	0.046	0.147	0.883	-0.00241	0.001	-2.128	**0.033**	0.05221				-0.00080	0.000	-5.428	**0.000**
WHITE HAKE	502	-0.41310	0.305	-1.353	0.177	-0.06444	0.142	-0.453	0.651	-0.00024	0.002	-0.098	0.922	0.01387	0.006	2.440	**0.015**				
RED HAKE	161	1.49532	0.968	1.544	0.125	-0.07232	0.283	-0.255	0.799	-0.00357	0.006	-0.603	0.548	-0.02140	0.024	-0.889	0.375				
SILVER HAKE	569	0.26356	0.210	1.255	0.210	-0.22045	0.072	-3.053	**0.002**	0.00147	0.001	1.463	0.144	-0.01115	0.007	-1.582	0.114				
POLLOCK	295	-4.83477	2.436	-1.985	**0.048**	-0.37725	0.266	-1.420	0.157	-0.00761	0.003	-2.606	**0.010**	0.18407	0.091	2.032	**0.043**	-0.00138	0.001	-1.696	0.091
REDFISH	1137	-0.25187	0.187	-1.348	0.178	0.36065	0.065	5.537	**0.000**	-0.00247	0.001	-3.004	**0.003**	0.08527				-0.00206	0.000	-5.175	**0.000**
TURBOT	337	-1.74078	0.536	-3.246	**0.001**	0.70465	0.135	5.230	**0.000**	-0.00206	0.001	-1.495	0.136	0.12648				-0.00182	0.000	-3.871	**0.000**
PLAICE	1783	0.81819	0.091	9.022	**0.000**	-0.48639	0.053	-9.124	**0.000**	-0.00099	0.001	-1.051	0.294	-0.01640	0.003	-4.954	**0.000**				
WITCH	669	2.29576	0.424	5.415	**0.000**	-0.28229	0.105	-2.682	**0.007**	-0.00121	0.001	-0.852	0.395	-0.14992				0.00264	0.001	4.784	**0.000**
YELLOWTAIL	681	0.36852	0.164	2.242	**0.0253**	0.07255	0.08	0.903	0.3669	-0.00294	0.003	-1.092	0.2754	-0.00351	0.007	-0.534	0.5933				
WINTER FLOUNDER	216	1.22390	0.555	2.205	**0.029**	0.15450	0.185	0.835	0.404	-0.01213	0.010	-1.242	0.216	-0.01890	0.016	-1.199	0.232				
HERRING	550	1.90404	0.345	5.513	**0.000**	0.36282	0.106	3.434	**0.001**	-0.00070	0.001	-0.537	0.592	-0.07674	0.014	-5.475	**0.000**				
ALEWIFE	113	-1.07347	0.985	-1.090	0.278	1.03008	0.353	2.921	**0.004**	-0.02208	0.005	-4.064	**0.000**	0.06417	0.047	1.371	0.173				
CAPELIN	99	5.11122	1.783	2.867	**0.005**	-0.67313	0.420	-1.601	0.113	0.07041	0.012	5.744	**0.000**	-0.75031	0.158	-4.751	**0.000**				
LONGFIN HAKE	130	3.16986	1.775	1.786	0.077	-1.44867	0.366	-3.954	**0.000**	0.00049	0.003	0.140	0.889	-0.34154				0.00826	0.003	2.640	**0.009**
ROSEFISH	130	0.07646	0.901	0.085	0.932	-0.73909	0.231	-3.194	**0.002**	-0.01929	0.003	-5.647	**0.000**	0.28297				-0.00536	0.002	-2.178	**0.031**
THORNY SKATE	353	-0.32941	0.225	-1.461	0.145	0.24306	0.226	1.076	0.283	0.00308	0.003	1.101	0.272	0.00449	0.007	0.653	0.514				
DOGFISH	258	3.13440	0.542	5.779	**0.000**	0.19659	0.240	0.821	0.413	-0.00832	0.003	-3.133	**0.002**	-0.03191	0.005	-6.500	**0.000**				
LONGHORN SCULPIN	494	-0.30544	0.313	-0.976	0.330	-0.30535	0.170	-1.793	0.074	-0.00912	0.003	-3.128	**0.002**	0.02758	0.011	2.540	**0.011**				
MAILED SCULPIN	133	-1.51556	0.595	-2.548	**0.012**	0.57964	0.666	0.870	0.386	0.00587	0.010	0.595	0.553	0.11817	0.055	2.158	**0.033**				
SEA RAVEN	245	1.99076	0.809	2.462	**0.015**	-1.14665	0.292	-3.930	**0.000**	-0.00394	0.009	-0.418	0.676	-0.09500	0.046	-2.061	**0.040**	0.00122	0.001	1.582	0.115
ALLIGATORFISH	87	-3.40662	1.123	-3.034	**0.003**	-0.07232	0.502	-0.144	0.886	0.00358	0.013	0.277	0.783	0.29732	0.077	3.863	**0.000**				
SEA POACHER	99	0.98734	1.231	0.802	0.425	0.26478	0.314	0.844	0.401	-0.00635	0.011	-0.552	0.582	-0.00457	0.039	-0.118	0.906				
SANDLANCE	253	-8.86054	3.209	-2.761	**0.006**	-0.64351	0.153	-4.196	**0.000**	0.00289	0.012	0.248	0.805	0.82570	0.332	2.487	**0.014**	-0.01612	0.009	-1.883	0.061
BLENNY	128	-7.27249	3.052	-2.383	**0.019**	-0.99305	0.349	-2.845	**0.005**	0.02580	0.014	1.885	0.062	0.42245				-0.00648	0.003	-2.071	**0.040**
SHANNY	138	-2.44389	0.615	-3.973	**0.000**	-0.09675	0.162	-0.596	0.552	0.00587	0.005	1.278	0.204	0.18931	0.042	4.503	**0.000**				
SHORTFIN SQUID	305	2.53354	0.524	4.833	**0.000**	-0.20286	0.158	-1.281	0.201	-0.00688	0.002	-3.250	**0.001**	-0.08499	0.034	-2.485	**0.013**				
COD outlier removed)	618	1.18714	0.422	2.814	**0.005**	0.25092	0.151	1.667	0.096	0.01419	0.002	6.771	**0.000**	-0.10876				0.00103	0.000	4.839	**0.000**

TABLE 4. Mixed effects model results for species sampled sufficiently to consider length effects. Bold font emphasizes probabilities under 0.05.

Species	N	DF	Intercept	SE	T	P	Period	SE	T	P	Depth	SE	T	P	Length	SE	T	P	quadratic	SE	T	P
COD	650	587	0.62195	0.531	1.172	0.242	0.46247	0.259	1.787	0.074	0.00898	0.005	1.535	0.125	-0.06106				0.00054	0.000	2.608	**0.009**
HADDOCK	1487	1418	0.18994	0.186	1.021	0.307	-0.82516	0.130	-6.336	**0.000**	0.00194	0.002	0.991	0.322	0.00233	0.003	0.925	0.355				
WHITE HAKE	502	457	-0.41202	0.351	-1.174	0.241	0.01545	0.191	0.081	0.936	0.00056	0.003	0.197	0.844	0.01041	0.006	1.732	0.084				
RED HAKE	161	139	0.56483	1.067	0.530	0.597	0.13630	0.356	0.382	0.703	0.00156	0.007	0.227	0.820	-0.01708	0.023	-0.734	0.464				
SILVER HAKE	569	517	-0.56831	0.613	-0.923	0.356	-0.34098	0.172	-1.977	**0.049**	-0.00201	0.003	-0.765	0.444	0.08647	0.051	1.696	0.091	-0.00178	0.001	-1.623	0.105
POLLOCK	295	17	-6.69539	2.314	-2.893	**0.004**	0.00791	0.009	0.859	0.402	-0.59360	0.706	-0.841	0.412	0.18643				-0.00143	0.001	-1.937	**0.054**
REDFISH	1137	1057	-1.25196	0.299	-4.181	**0.000**	0.51689	0.135	3.840	**0.000**	0.00699	0.001	4.699	**0.000**	0.05790				-0.00174	0.001	-3.419	**0.001**
TURBOT	337	18	-0.89333	0.690	-1.295	0.196	0.43926	0.340	1.291	0.213	-0.00015	0.002	-0.063	0.951	0.06509				-0.00112	0.000	-2.400	**0.017**
PLAICE	1783	1695	0.67235	0.168	4.001	**0.000**	-0.13784	0.132	-1.041	0.298	-0.00248	0.002	-1.172	0.241	-0.01321	0.003	-3.951	**0.000**				
WITCH	669	603	1.95821	0.507	3.863	**0.000**	-0.30259	0.180	-1.685	0.093	0.00104	0.002	0.449	0.653	-0.14536				0.00254	0.001	4.263	**0.000**
YELLOWTAIL	681	630	0.39886	0.293	1.362	0.174	-0.09003	0.145	-0.623	0.534	-0.01387	0.005	-2.676	**0.008**	0.01485	0.008	1.879	0.061				
WINTER FLOUNDER	216	193	-0.58926	1.677	-0.351	0.726	0.32407	0.357	0.908	0.365	-0.00002	0.015	-0.001	0.999	0.07239	0.111	0.655	0.513				
HERRING	550	479	-0.36084	0.833	-0.433	0.665	0.14608	0.300	0.488	0.626	0.00545	0.004	1.241	0.215	0.11713				-0.00458	0.002	-3.039	**0.003**
ALEWIFE	113	16	-1.07347	0.985	-1.090	0.279	1.03007	0.353	2.921	**0.010**	-0.02208	0.005	-4.063	**0.001**	0.06417	0.047	1.371	0.174				
CAPELIN	99	15	-2.12703	5.047	-0.421	0.675	0.21917	0.882	0.248	0.807	0.03669	0.022	1.694	0.111	0.25450	0.795	0.320	0.750				
LONGFIN HAKE	130	10	3.0208	1.837	1.645	0.1028	-0.8484	0.629	-1.348	0.2074	-0.0022	0.006	-0.371	0.7181	-0.2991				0.0075	0.003	2.445	**0.016**
ROSEFISH	130	10	-0.39489	1.114	-0.355	0.724	-0.83577	0.519	-1.612	0.138	-0.02099	0.005	-4.317	**0.002**	0.36352				-0.00695	0.003	-2.738	**0.007**
THORNY SKATE	353	34	-0.06838	0.300	-0.228	0.820	0.24405	0.271	0.902	0.373	0.00229	0.003	0.709	0.483	-0.00199	0.007	-0.274	0.784				
DOGFISH	258	12	5.24626	1.675	3.132	**0.002**	-0.00027	0.005	-0.050	0.961	0.02442	0.316	0.077	0.940	-0.12381	0.053	-2.326	**0.021**	0.00072	0.000	1.700	0.091
LONGHORN SCULPIN	494	443	0.29998	0.656	0.457	0.648	-0.09581	0.212	-0.452	0.651	-0.00505	0.004	-1.287	0.199	-0.05019	0.054	-0.938	0.349				
MAILED SCULPIN	133	20	-1.13672	0.774	-1.469	0.145	0.45482	0.729	0.624	0.540	-0.00780	0.015	-0.520	0.609	0.14502	0.056	2.599	**0.011**				
SEA RAVEN	245	213	0.71423	0.686	1.041	0.299	-0.83629	0.363	-2.306	**0.022**	-0.00522	0.011	-0.489	0.625	-0.01266	0.013	-0.993	0.322				
ALLIGATORFISH	87	64	-0.20925	2.160	-0.097	0.923	-0.12784	0.487	-0.262	0.794	0.00023	0.013	0.018	0.986	-0.37038	0.409	-0.906	0.369				
SEA POACHER	99	14	0.98735	1.231	0.802	0.425	0.26477	0.314	0.844	0.413	-0.00635	0.011	-0.552	0.589	-0.00457	0.039	-0.118	0.906				
SANDLANCE	253	19	-9.14905	3.682	-2.485	**0.014**	-0.12813	0.639	-0.201	0.843	-0.00602	0.033	-0.181	0.858	0.84467	0.369	2.289	**0.023**	-0.01554	0.009	-1.642	0.102
BLENNY	126	9	-7.27322	3.052	-2.383	**0.019**	-0.99319	0.349	-2.844	**0.019**	0.02580	0.014	1.885	0.092	0.42249				-0.00648	0.003	-2.071	**0.041**
SHANNY	138	18	-7.02772	2.545	-2.762	**0.007**	-0.00225	0.010	-0.228	0.822	-0.22238	0.364	-0.610	0.549	1.06863				-0.03550	0.017	-2.117	**0.036**
SHORTFIN SQUID	305	252	0.88704	0.530	1.673	0.095	-0.34515	0.370	-0.933	0.352	-0.00275	0.003	-0.920	0.358	0.00194	0.021	0.094	0.926				

Table 5. Stratified estimates of Scotian Shelf Summer Survey numbers for 2004, conducted by the Teleost. Length group estimates are provided where past assessments of stock status indicate relevance. Values of NA represent calibration models with no significant effects at P <= 0.05.

	Estimates for All Fish Uncalibrated Estimates		Estimates for Measured Fish Only Uncalibrated Estimates			Calibrated Estimates Fixed Effects Models			Mixed Effects Models			
Year	Number per Tow	Standard Error	Small Fish	Large Fish	Number per Tow	Small Fish	Large Fish	Number per Tow	Small Fish	Large Fish	Number per Tow	Length split
Cod	3.280	0.729	2.929	0.453	3.382	1.878	0.906	2.785	2.824	0.459	3.283	SmallFish <= 53cm
(Cod - outlier removed)						2.918	0.507	3.425				
Haddock	43.797	8.440	39.493	4.226	43.720	42.422	3.743	46.165	37.166	3.993	41.159	SmallFish <= 41cm
White Hake	2.131	0.568	1.827	0.321	2.148	2.067	0.395	2.462	NA	NA	NA	
Red Hake	1.702	0.427			1.712			2.899			NA	
Silver Hake	83.029	37.860			82.950			85.227			87.366	
Pollock	3.106	0.907	0.865	2.276	3.141	0.502	2.532	3.034	0.229	1.372	1.601	SmallFish <= 42cm
Redfish	60.810	16.474	34.701	26.501	61.202	63.609	43.388	107.000	39.730	30.287	70.017	SmallFish <= 22cm
Turbot	1.429	0.272	1.458	0.004	1.462	2.289	0.003	2.292	1.648	0.002	1.649	SmallFish <= 56cm
Plaice	28.966	6.332	24.226	4.772	28.998	31.221	4.710	35.931	28.737	4.563	33.301	SmallFish <= 30cm
Witch	3.771	0.655	2.249	1.546	3.795	2.475	1.832	4.307	2.276	1.622	3.898	SmallFish <= 30cm
Yellowtail	17.829	5.024	16.513	1.035	17.548	20.343	1.271	21.614	19.440	1.502	20.942	SmallFish <= 30cm
Winter Flounder	4.411	1.157			4.841			6.546			NA	
Herring	213.093	72.154			212.440			430.480			276.830	
Alewife	0.704	0.134			0.723			0.608			0.608	
Capelin	1.614	1.060			1.582			349.230			NA	
Longfin Hake	0.470	0.163			0.463			0.345			0.282	
Rosefish	2.072	0.794			2.039			2.211			2.451	
Thorny Skate	1.540	0.500			1.527			2.019			NA	
Dogfish	30.391	9.835	30.256	6.254	36.510	54.998	8.896	63.894	35.282	5.553	40.835	SmallFish <= 75cm
Longhorn Sculpin	3.017	0.576			3.056			2.976			NA	
Mailed Sculpin	1.891	0.576			1.943			1.838			1.986	
Sea Raven	0.716	0.155			0.740			0.797			0.670	
Alligatorfish	0.917	0.435			1.026			0.861			NA	
Sea Poacher	0.409	0.140			0.413			0.722			0.722	
Sandlance	119.858	55.313			120.340			247.210			425.770	
Blenny	0.737	0.241			0.731			1.676			1.705	
Shanny	14.950	8.441			15.916			20.709			24.351	
Shortfin Squid	119.340	72.976			118.090			170.460			170.280	

TABLE 6. Raw counts and relative set quantities for species sampled sufficiently to consider length effects

Species	Needler	Teleost	Sets Needler > Teleost	Sets Teleost > Needler
COD	870	2547	37	29
HADDOCK	6154	6399	32	46
WHITE HAKE	663	589	21	21
RED HAKE	221	130	10	11
SILVER HAKE	3747	3488	24	27
POLLOCK	790	964	11	9
REDFISH	21151	14201	48	40
TURBOT	979	708	11	10
PLAICE	5432	4509	57	43
WITCH	1731	1544	34	31
YELLOWTAIL	2655	2161	27	24
WINTER FLOUNDER	503	376	11	9
HERRING	5744	5765	39	34
ALEWIFE	172	182	10	9
CAPELIN	3842	3344	13	5
LONGFIN HAKE	191	242	8	5
ROSEFISH	323	339	7	6
THORNY SKATE	327	297	20	17
DOGFISH	2882	2217	10	5
LONGHORN SCULPIN	831	930	22	33
MAILED SCULPIN	283	294	12	11
SEA RAVEN	169	207	12	19
ALLIGATORFISH	84	116	10	11
SEA POACHER	131	75	12	5
SANDLANCE	45927	22031	16	6
BLENNY	148	64	8	4
SHANNY	1268	928	14	7
SHORTFIN SQUID	2059	1418	33	23

TABLE 7. Traditional fixed effects model coefficients (significant at P<=0.05) for species sampled sufficiently to consider length effects. Italics flag species for which a coefficient became significant during stepwise term deletion. Bold font emphasizes species with significant (P<=0.05) coefficients.

Species	N	Intercept	SE	T	P	Period	SE	T	P	Depth	SE	T	P	Length	SE	T	P	quadratic	SE	T	P
COD	650					1.82330	0.137	13.324	0.000	0.01105	0.003	4.128	0.000	-0.12570				0.00130	0.000	10.176	0.000
HADDOCK	1487	-0.64644	0.121	-5.335	0.000					-0.00238	0.001	-2.136	0.033	0.05218				-0.00080	0.000	-5.428	0.000
WHITE HAKE	502													0.00345	0.001	2.529	0.012				
RED HAKE	161	0.52668	0.119	4.418	0.000																
SILVER HAKE	589					-0.20876	0.072	-2.907	0.004	0.00172	0.000	3.823	0.000								
POLLOCK	295	-1.35191	0.470	-2.876	0.004					-0.00587	0.003	-2.095	0.037	0.03362	0.010	3.456	0.001				
REDFISH	1137					0.34353	0.064	5.375	0.000	-0.00295	0.001	-3.981	0.000	0.06609				-0.00163	0.000	-6.919	0.000
TURBOT	337	-1.68766	0.531	-3.177	0.002	0.69975	0.134	5.228	0.000					0.11020				-0.00165	0.000	-3.651	0.000
PLAICE	1783	0.77937	0.083	9.414	0.000	-0.49678	0.052	-9.481	0.000					-0.01737	0.003	-5.466	0.000				
WITCH	669	2.20113	0.411	5.358	0.000	-0.29036	0.105	-2.771	0.006					-0.15356				0.00273	0.001	5.045	0.000
YELLOWTAIL	681	0.39323	0.088	4.492	0.000					-0.00566	0.002	-2.335	0.020								
WINTER FLOUNDER	216	1.09714	0.396	2.772	0.006									-0.02889	0.014	-2.086	0.038				
HERRING	550	1.89090	0.346	5.465	0.000	0.38750	0.095	4.060	0.000					-0.07919	0.013	-5.926	0.000				
ALEWIFE	113					1.27692	0.251	5.078	0.000	-0.01958	0.004	-5.085	0.000								
CAPELIN	99	4.25169	1.607	2.646	0.010					0.07316	0.012	5.890	0.000	-0.73029	0.148	-4.936	0.000				
LONGFIN HAKE	130					-1.31209	0.352	-3.726	0.000					-0.07440				0.00294	0.001	2.629	0.010
ROSEFISH	130					-0.73307	0.220	-3.338	0.001	-0.01921	0.003	-5.886	0.000	0.28990				-0.00554	0.001	-4.520	0.000
THORNY SKATE	353									0.00235	0.001	2.406	0.017								
DOGFISH	258	3.31498	0.496	6.680	0.000					-0.00820	0.003	-3.092	0.002	-0.03196	0.005	-6.512	0.000				
LONGHORN SCULPIN	494					-0.31576	0.170	-1.857	0.064	-0.01060	0.002	-4.252	0.000	0.01832	0.005	3.456	0.001				
MAILED SCULPIN	133	-1.40347	0.541	-2.596	0.010									0.13308	0.052	2.583	0.011				
SEA RAVEN	245	0.92683	0.349	2.656	0.008	-1.05438	0.266	-3.962	0.000					-0.02448	0.011	-2.170	0.031				
ALLIGATORFISH	87	-3.19037	0.755	-4.226	0.000									0.29293	0.074	3.944	0.000				
SEA POACHER	99	0.55847	0.150	3.721	0.000																
SANDLANCE	253	-2.92270	0.563	-5.191	0.000	-0.63846	0.135	-4.730	0.000					0.20867	0.029	7.275	0.000				
BLENNY	128	-5.85765	2.774	-2.112	0.037	-0.93481	0.341	-2.738	0.007					0.44614				-0.00666	0.003	-2.237	0.027
SHANNY	138	-2.05879	0.526	-3.911	0.000									0.18989	0.042	4.531	0.000				
SHORTFIN SQUID	305	2.39316	0.512	4.678	0.000					-0.00683	0.002	-3.209	0.001	-0.08618	0.034	-2.520	0.012				
COD (outlier removed)	618	1.31584	0.414	3.176	0.002					0.01391	0.002	6.692	0.000	-0.10430				0.00098	0.000	4.669	0.000

TABLE 8. Mixed effects model coefficients (significant at P<=0.05) for species sampled sufficiently to consider length effects. Italics flag species for which a coefficient became significant during stepwise term deletion. Bold font emphasizes species with significant (P<=0.05) coefficients.

Species	Intercept	SE	T	P	Period	SE	T	P	Depth	SE	T	P	Length	SE	T	P	quadratic	SE	T	P
COD					0.56277	0.245	2.301	0.022	0.00909	0.004	2.171	0.030	-0.04359				0.00038	0.000	2.583	0.010
HADDOCK	0.38210	0.119	3.201	0.001	-0.79262	0.128	-6.192	0.000												
WHITE HAKE																				
RED HAKE																				
SILVER HAKE					-0.30993	0.155	-2.003	0.046					0.00905	0.005	2.004	0.046				
POLLOCK	-6.39480	2.082	-3.072	0.002									0.19020				-0.00150	0.001	-1.979	0.049
REDFISH	-1.25196	0.299	-4.181	0.000	0.51689	0.135	3.840	0.000	0.00699	0.001	4.699	0.000	0.05790				-0.00174	0.001	-3.419	0.001
TURBOT													0.02882				-0.00067	0.000	-3.191	0.002
PLAICE	0.46357	0.110	4.228	0.000									-0.01396	0.003	-4.215	0.000				
WITCH	1.85420	0.446	4.153	0.000									-0.13790				0.00240	0.001	4.085	0.000
YELLOWTAIL									-0.00918	0.004	-2.346	0.019	0.01998	0.006	3.233	0.001				
WINTER FLOUNDER																				
HERRING													0.12404				-0.00466	0.001	-5.489	0.000
ALEWIFE					1.27690	0.251	5.078	0.000	-0.01960	0.004	-5.085	0.000								
CAPELIN																				
LONGFIN HAKE													-0.09807				0.00334	0.001	2.454	0.016
ROSEFISH									-0.02229	0.004	-5.196	0.000	0.28298				-0.00502	0.002	-2.721	0.008
THORNY SKATE																				
DOGFISH	2.52610	0.362	6.984	0.000									-0.03360	0.005	-7.227	0.000				
LONGHORN SCULPIN																				
MAILED SCULPIN	-1.40250	0.572	-2.452	0.016									0.14040	0.053	2.631	0.010				
SEA RAVEN					-0.70275	0.278	-2.527	0.012												
ALLIGATORFISH																				
SEA POACHER	0.55845	0.150	3.721	0.000																
SANDLANCE	-3.78760	0.521	-7.276	0.000									0.24790	0.024	10.236	0.000				
BLENNY	-5.97770	2.798	-2.136	0.035	-1.05520	0.402	-2.625	0.025					0.45620				-0.00680	0.003	-2.282	0.024
SHANNY	-7.24140	2.450	-2.956	0.004									1.06280				-0.03530	0.017	-2.119	0.036
SHORTFIN SQUID													0.02101	0.011	1.940	0.054				

TABLE 9. Recommended calibration coefficients, derived from mixed effects models.

Species	Intercept	Period	Depth	Length (Linear Term)	Length (Quadratic Term)
COD		0.56277	0.00909	-0.04359	0.00038
HADDOCK	0.38210	-0.79262			
SILVER HAKE		-0.30993		0.00905	
POLLOCK	-6.39480			0.19020	-0.00150
REDFISH	-1.25196	0.51689	0.00699	0.05790	-0.00174
TURBOT				0.02882	-0.00067
PLAICE	0.46357			-0.01396	
WITCH	1.85420			-0.13790	0.00240
YELLOWTAIL			-0.00918	0.01998	
HERRING				0.12404	-0.00466
ALEWIFE		1.27690	-0.01960		
LONGFIN HAKE				-0.09807	0.00334
ROSEFISH			-0.02229	0.28298	-0.00502
DOGFISH	2.52610			-0.03360	
MAILED SCULPIN	-1.40250			0.14040	
SEA RAVEN		-0.70275			
SEA POACHER	0.55845				
SANDLANCE	-3.78760			0.24790	
BLENNY	-5.97770	-1.05520		0.45620	-0.00680
SHANNY	-7.24140			1.06280	-0.03530
SHORTFIN SQUID				0.02101	

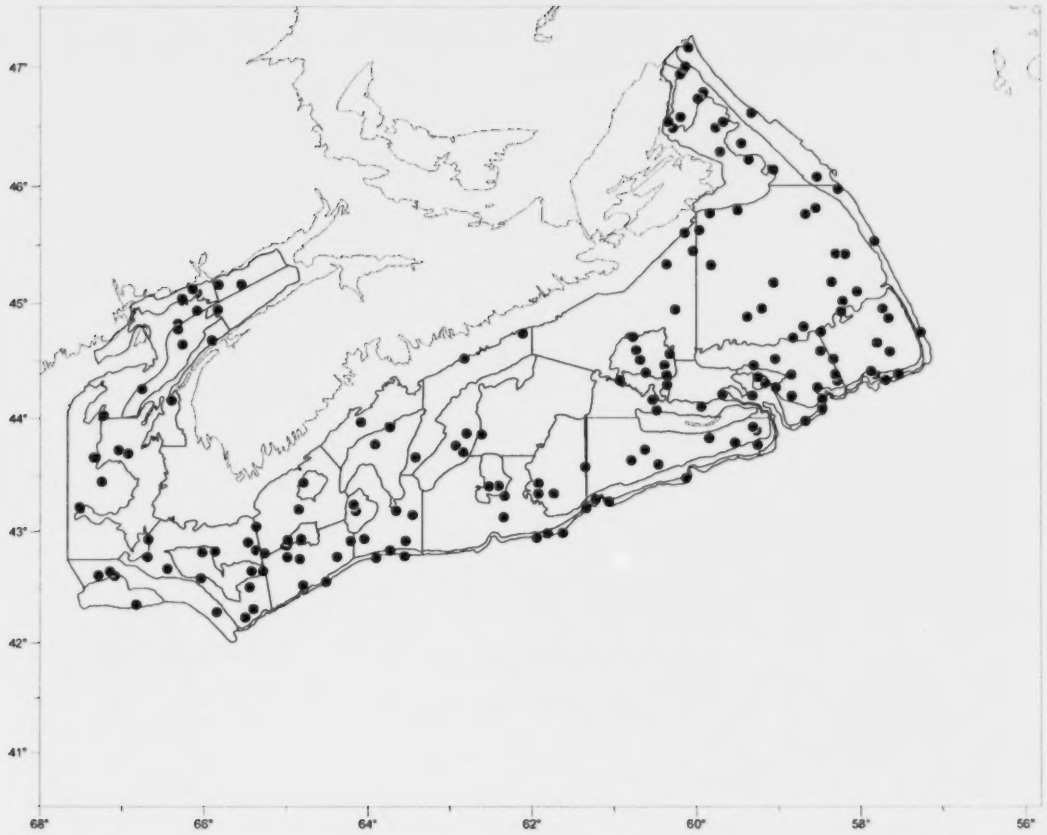

Figure 1. Locations of valid set pairs used in analyses. The 4VWX Summer Survey strata are also shown.

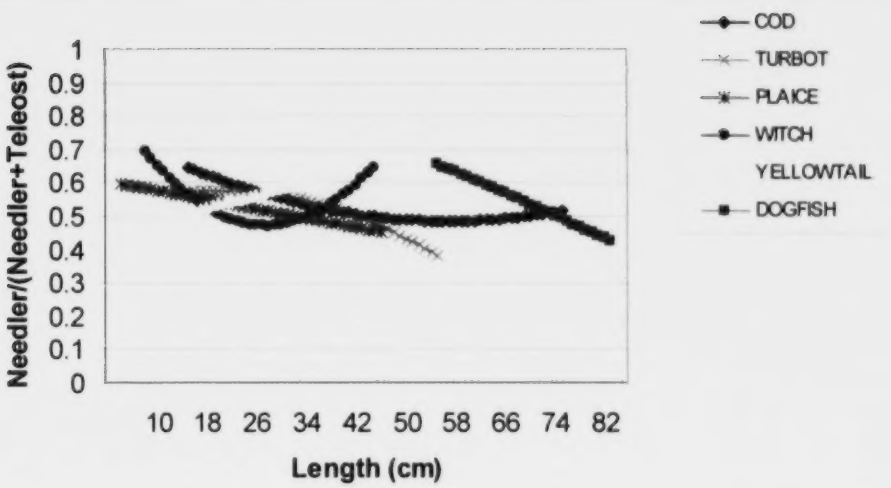

Figure 2. Relative catchabilities of typical groundfish species exhibiting different selectivities at length between vessels (significant at P<=0.05). The values are predictions from mixed-effects models, and values associated with trailing portions of a length distribution are omitted.

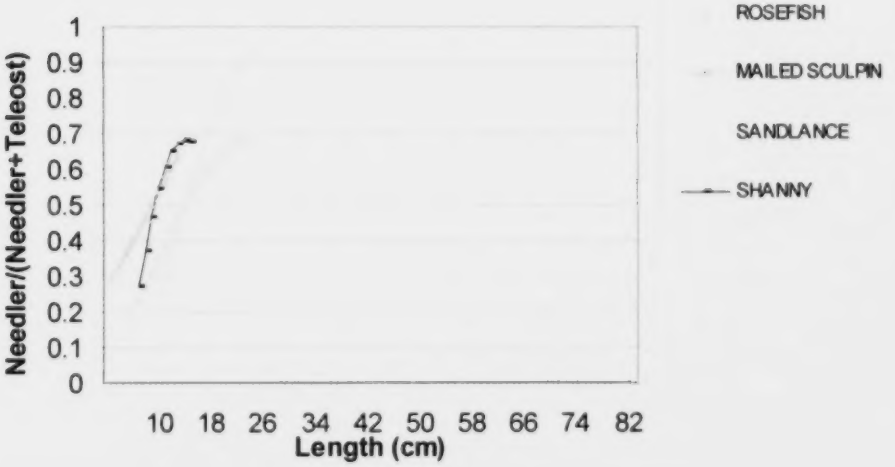

Figure 3. Relative catchabilities of very small (mailed sculpin, shanny, rosefish, sandlance) fish species exhibiting different selectivities at length between vessels (significant at P<=0.05). The values are predictions from mixed-effects models, and values associated with trailing portions of a length distribution are omitted.

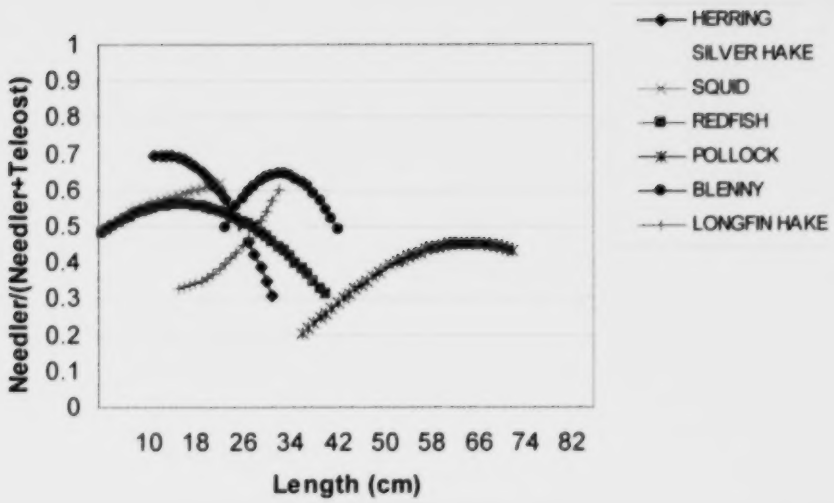

Figure 4. Relative catchabilities of uncategorized species exhibiting different selectivities at length between vessels (significant at P<=0.05). The values are predictions from mixed-effects models, and values associated with trailing portions of a length distribution are omitted.

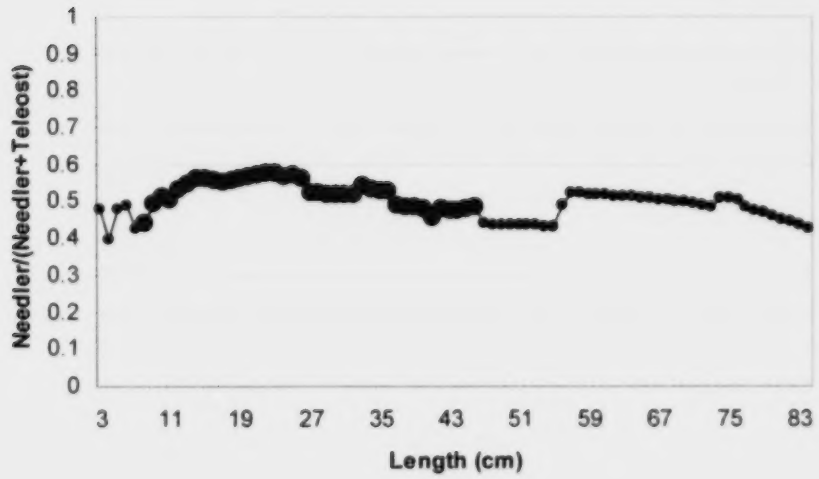

Figure 5. Mean relative catchabilities at length across all species exhibiting different selectivities at length between vessels (significant at P<=0.05). Larger symbols denote fish lengths represented by 5 or more of the 17 species depicted in Figures 2-4.

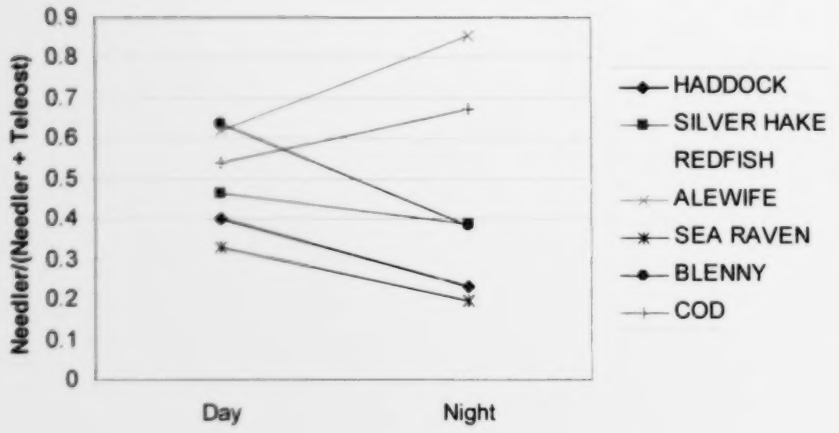

Figure 6. Relative catchabilities of species exhibiting diel differences in catchability between vessels (significant at P<=0.05). The values are predictions from mixed-effects models.

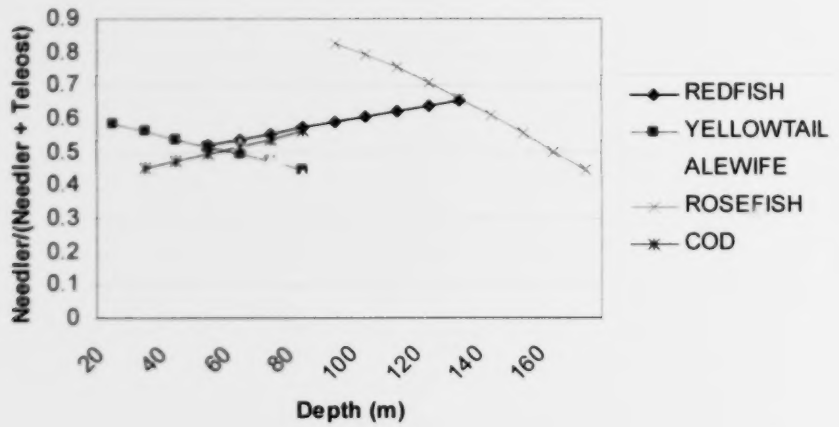

Figure 7. Relative catchabilities of species exhibiting differences in catchability between vessels with depth (significant at P<=0.05). The values are predictions from mixed-effects models, and values associated with trailing portions of a depth distribution are omitted.